Final Technical Report

Turbulent Dissipation in Frontal Zones from Hot-wire Measurements in the MICROFRONTS Experiment

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14. ABSTRACT Measurements of turbulent dissipation of kinetic energy have been taken of synoptic and smallscale density frontal passages during the MICROFRONTS (MARCH 1999, Kansas) field program. It is revealed that there is a significant increase of turbulent kinetic energy during each passage of the frontal transition zone. Data analyses suggest a linear relationship between the frontal width and the enhanced kinetic energy dissipation rate. A theoretical development supports this observational result. The conclusion is, however, tentative, because the data are limited and some physical processes have not been taken into account.

(continued)

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14. Abstract (Continued)

The source of turbulence associated with a shallow density front and trailing current is also analyzed. The characteristics of dissipation in this small scale event, and the heat budget associated with the front and current are determined. Other analyses carried out as part of the front-boundary layer focus of this investigation, include the investigation of the turbulence and heat budget characteristics of the lowest 10 meters of the atmosphere as a function of static stability. and the characteristics of frontogenesis in the presence of inertial oscillations. The various results obtained are all related to the development of parameterization schemes that are required by weather prtediction models.

1. Introduction

This investigation is principally directed to the analysis of data obtained during the MICROFRONTS Experiment, and to use these data to examine the characteristics of turbulent dissipation that is associated with the passages of atmospheric fronts in the Earth's boundary layer. Theoretical analyses that are intended to examine frontal processes are also carried out.

MICROFRONTS was organized to collect data in the turbulent boundary layer, particularly to examine kinetic energy dissipation in prefrontal, transition zone and in postfrontal regimes. The distinguishing characteristic of the MICROFRONTS field program was the collection of high frequency (9.6kHz) data from either one or two hot-wire anemometers located at 3 m above the ground. Data were collected during the passage of two cold fronts and the passage of a shallow density front. The research carried out during the grant period, 1 June 1997 - 30 September 1999, was carried out with the support of the Air Force Office of Scientific Research and the Atmospheric Technology Division of the National Center for Atmospheric Research, which supplied observational facilities through the deployment funds of the National Science Foundation and personnel and facilities from the Surface and Soundings Facility of NCAR.

2. Accomplishments

The facilities available were the NCAR ASTER system, which is a cluster of three 10 m towers. Two clusters of towers were employed, spaced 300m apart on a southwest-northeast line. All the instrumentation on these towers, the site in De Graff, Kansas, and methods of handling the data are described in detail in Blumen, Grossman and Piper (1999). The principal events that were observed during the observational period, 1-30 March 1995, were two atmospheric cold fronts and a shallow density front. One cold front passed during the early evening, and the second passed during the early afternoon. The density front passed in the early evening. The analyses of the two evening passages has been completed, and the results published. The references are Blumen, Grossman and Piper (1999) and Blumen and Piper (1999). The most significant features of the analyses will be presented. Details are available in the references.

The cold front passed the ASTER facility at 2030 Central Standard Time (CST) on 19 March 1995, and the density front passed at 2145 CST on 17 March 1995. The hot-wire anemometer and sonics on the ASTER towers provided measurements during the prefrontal, transition zone and post frontal phases of each passage.

The long-term goal of the PI's research is to examine the effect of boundary layer processes on frontal passages and to examine the physical mechanism which leads to the equilibration of a frontal zone. The two fronts considered in these analyses are of considerably different scales and exhibit different dissipation rates of kinetic energy during their passages past the tower sensors. These events were used to determine a relation between the characteristic width of the frontal zones and the measured dissipation rates. It was found that there is a linear relationship between the width and the dissipation rate. A theoretical analysis, which uses a simple model of nonlinear frontogenesis, confirms that a linear relationship can be supported. The details of the analysis appear in Blumen and Piper (1999). Although the analysis appears to be in agreement with the observations, there are important limitations. Frontal passages during the period of convective heating were not considered (the analysis of the daytime front is underway), the dissipation measurements were restricted to the 3 m level, and condensation was not a factor. All of these considerations need to be included, if this information is to be used, ultimately, for the development of parameterization schemes for synoptic and mesoscale prediction models.

The model used in the theoretical development by Blumen and Piper (1999) is considered to be a simplification that may be improved upon. Blumen (1999) has considered a nonlinear frontal model, which is characterized by the presence of inertial oscillations during the process of frontogenesis. The theoretical development shows that the wind field from the inertial oscillation can enhance frontogenesis during the first half-cycle of the inertial period, but inhibits frontogenesis during the second half cycle. This feature is yet another feature, together with the presence of internal gravity waves, that need to be considered to gain a comprehensive understanding of frontal zone equilibration. The inclusion of an Ekman boundary layer in this model, with inertial oscillations, is presently being investigated.

The data collected during MICROFRONTS also revealed some interesting features concerning the regimes of static stability and the presence of turbulent activity in the layer closest to the ground. The details of the relationship between the weakly stable, transition and strongly stable regimes, and the presence of turbulence and the characteristics of heat flux associated with each regime are provided by Mahrt et al. (1998). This analysis does not provide evidence for the type of phenomena that occur in a stably stratified boundary layer, only properties of the motion as a function of stability. The stable nighttime surface layer under light wind conditions is usually relatively quiescent:both convective and mechanical instabilities and turbulence tend to be suppressed. Yet quiescent periods may be interrupted by turbulent bursts. The source(s) of these bursts is frequently unknown. There are suggestions that they are produced by breaking Kelvin-Helmholtz billows that may exist along an undulating interface in the boundary layer that separates layers of different static stability. Alternatively, the bursts may represent patches of turbulence, generated elsewhere, that are advected past a fixed sensor.

Work has been carried out with MICROFRONTS data to isolate the source of episodic turbulence in one specific event:the passage of a shallow density current on 17 March 1995. This event was observed when it passed each tower group of the ASTER facility. The specific details of the observed event, the heat budget during passage, the dissipation characteristics and a theoretical analysis of the balance between dissipation and frontal width are all presented in Blumen, Grossman and Piper (1999). The density current passed the first group of towers (south tower array) at 2145 CST and the significant features which identified this event as a density current lasted about 15 minutes. The head of the current, associated with the frontal passage, was estimated to be less than 20 m above the ground and the current behind the head was confined to a depth of less than 10 m. A burst of turbulence characterized the passage of the front. The transition zone was less than 200 m across, as determined by the measurements at the two tower groups, and a level of turbulence was maintained within the current until it became relatively indistinguishable near the end of the 15 minute period. There was a burst of turbulence at the 10 m level, that was not noticeable at the 3 m level, near the end of the period. This event could be associated with the breaking of a Kelvin Helmholtz billow, present at the interface between the density current and the ambient air above. This conjecture could not be established with the limited observations available. The present data do show that some turbulent bursts can be identified with drainage or density currents in a very stable nighttime boundary layer. The source of other bursts has not been definitely established. The episodic nature makes this type of activity difficult to identify and to parameterize in prediction models.

Future work associated with the analysis and modeling of NMICROFRONTS data is presently being prepared by Mark Piper as part of a Ph.D. thesis in the Program in Atmospheric and Oceanic Sciences, University of Colorado. Completion during the academic year 1999-2000 is anticipated.

3. Publications

1. Blumen, W. 1999:Inertial oscillations and frontogenesis in a zero potential vorticity model. Journal of Physical Oceanography, in press.

2. Blumen, W., Grossman, R.L., and Piper, M., 1999:Analysis of heat budget, dissipation and frontogenesis in a shallow density current. Boundary Layer Meteorology, 91, 281-306.

3. Blumen, W. and Piper, M., 1999:The frontal width problem. Journal of the Atmospheric Sciences, 56, 3167-3172.

4. Mahrt L., Sun, J., Blumen, W., Delay, T., and Oncley, S., 1998: Nocturnal boundary layer regimes. Boundary Layer Meteorology, 88, 225-278.

4. Interactions

4.1 Conference Presentations

1. American Meteorological Society Conference on Boundary Layers and Turbulence. 28 July-1 August, 1997, Vancouver, B.C., Canada. Effects of a dry cold front passage on surface layer turbulence, and Sampling of coherent structures conditioned on bursts of kinetic energy dissipation rate.

2. American Meteorological Society Annual Conference. 12-16 January 1998. Observations of inertial oscillations in the vicinity of fronts, and Hot-wire anemometer measurements of dissipation in surface layer turbulence.

3. American Meteorological Society Conference on Boundary Layers and Turbulence. 10-15 January 1999. Analysis of dissipation in fronts.

4. American Meteorological Society Conference on Atmospheric and Oceanic Fluid Dynamics. 7-11 June 1999. Inertial oscillations and frontogenesis in a zero potential vorticity flow.

4.2 MICROFRONTS Data Set

The MICROFRONTS hot-wire anemometer data set is maintained by the Joint Office of Scientific Services, University Corporation for Atmospheric Research. The contact is Dr. Nimal Gamage, JOSS, UCAR, P.O. Box 3000, Boulder Colorado, 80307. E-mail:gamage@ucar.edu.

4.3 Some articles using the MICROFRONTS data

Mahrt, L., 1998:Stratified atmospheric boundary layers and breakdown of models. J. Theor. and Comp. Fluid Dyn., 11. 263-279.

Mahrt, L., 1999:Stratified atmospheric boundary layers. Boundary Layer meteorology, 90, 375-396.

Howell, J. and Sun, J, 1999:Surface layer fluxes in stable conditions.` Boundary Layer Meteorology, 90, 495-520.

5. Personnel supported

Mark Piper, Graduate Research Assistant. Expected completion of Ph.D. thesis during academic year 1999-2000.

Julie Lundquist, Graduate research Assistant. Testing and evaluation of hot-wire anemometer probes.